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ScienceDirect
Fuel 87 (2008) 1534–1542
FUEL
www.fuelfirst.com

Firing a sub-bituminous coal in pulverized coal boilers configured for bituminous coals

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Received 5 June 2007; received in revised form 23 August 2007; accepted 23 August 2007
Available online 21 September 2007

Abstract

It is important to adapt utility boilers to sub-bituminous coals to take advantage of their environmental benefits while limiting operation risks. We discuss the performance impact that Adaro, an Indonesian sub-bituminous coal with high moisture content, has on opposite-wall and tangentially-fired utility boilers which were designed for bituminous coals. Numerical simulations were made with GLACIER, a computational-fluid-dynamic code, to depict combustion behavior. The predictions were verified with full-scale test results. For analysis of the operational parameters for firing Adaro coal in both boilers, we used EXPERT system, an on-line supervision system developed by Israel Electric Corporation. It was concluded that firing Adaro coal, compared to a typical bituminous coal, lowers NO_x and SO_2 emissions, lowers LOI content and improves fouling behavior but can cause load limitation which impacts flexible operation.

Keywords: Sub-bituminous coal; Pulverized coal combustion; NO_x emissions

1. Introduction

Pulverized coal-fired utility boilers are the reliable power generation infrastructure, responsible for most global electricity production. Since the environmental era (1970–), reducing combustion generated pollution is of major importance for existing coal plants [1]. Sub-bituminous coals have become an important alternative for emissions compliance because of their unique constituents and combustion characteristics, such as reduced NO_x and SO_2 emissions. However, firing sub-bituminous coals with high moisture content is unpopular because their high water content delays oxygen consumption which causes high unburned content in fly ash and elevated fuel–NO_x formation [2]. One major challenge for today's boiler operator's staff is to adapt steam generator systems for sub-bituminous coals in order to claim the substantial environmental benefits these fuels offer while limiting operation risks.

Firing Adaro, a sub-bituminous coal mined in Indonesia, can be a solution for emissions compliance because of its low sulfur, nitrogen and ash content and high volatile matter content, as can be seen in Table 1 where Adaro coal properties are summarized. Adaro coal has low sulfur content (0.1%) compared to typical bituminous coals, which can eliminate installation of expensive desulphurization facilities. It has low nitrogen (0.9%) and high volatile matter content (43–45%) which provides the prospect for substantial in situ NO_x control; therefore potentially no additional costs for post-combustion reduction. However, Adaro's high water content (25%) can cause higher NO_x formation as explained in the previous paragraph. Finally, since ash content (1.0–1.8%) is typically less than that of bituminous coals, so are costs associated with ash handling and disposal.

The purpose of this paper is to discuss the performance impact that this important fuel has on both

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0016-2361/$ - see front matter
doi:10.1016/j.fuel.2007.08.020

Table 1
Adaro coal properties

Property	
Proximate analysis (DCB)[a] *(wt%)*	
Total moisture	25.0
Residual moisture	14.5
Ash	1.0
Volatile matter	43.5
Fixed C	41.0
Gross CV (MJ kg^{-1}), wet	21.7
Net CV (MJ kg^{-1}), wet	20.3
Elemental analysis (daf)[b] *(wt%)*	
Carbon, C	73.8
Hydrogen, H	4.9
Nitrogen, N	0.9
Sulfur, S	0.10
Oxygen, O	20.3

[a] DCB – dry coal base.
[b] daf – dry ash free.

tangentially-fired and opposite-wall utility boilers of Israel Electric Corporation (IEC), in particular, but for other similar boilers, in general.

To predict the combustion behavior and pollutant emissions of Adaro coal in the pulverized-coal utility boilers, we combine experimental data from firing the coal in a test furnace and numerical simulations of the test furnace and the full-scale furnaces. Descriptions of our prediction method are found elsewhere and will not be included in this paper [3–5]. The simulations were done using a commercial computational-fluid-dynamic (CFD) code, GLACIER, developed and marketed by reaction engineering international (REI). We verified the full-scale model predictions with results from a series of full-scale tests done with Adaro coal fired by IEC.

For analysis of the operational parameters for firing Adaro coal in a boiler designed for bituminous coal combustion, we use EXPERT system, described by Chudnovsky et al. [6]. This is an on-line supervision system which was developed by IEC and is installed in their boilers. The purpose of this system is to quantify the performance of the combustion and heat transfer processes in real time, reporting continuously on the controlled parameter deviations from their reference values. For prediction purposes the supervision system is used in off-line mode as "what–if–then" mode.

2. Methodology

2.1. Combustion behavior prediction – GLACIER CFD code

For the prediction of combustion behavior we used the configured fireside simulator (CFS) which is a graphical user interface (GUI) developed by Reaction Engineering International (REI) for the purpose of running a preconfigured GLACIER model of a coal-fired furnace. GLACIER is a CFD code, developed by REI, used to model the physical and chemical processes occurring in utility boilers. Simulating coal combustion and pollutant formation is stressed in the model code [7], which accounts for radiant and convective heat transfer, turbulent two-phase mixing, devolatilization and heterogeneous coal particle reactions (char oxidation), equilibrium (CO_2, O_2, H_2O, SO_x and CO) and finite rate (NO_x) gas-phase chemical reactions [8]. NO_x prediction is done by post-processor calculation. Coal reactions are characterized by liquid vaporization, coal devolatilization, and char oxidation. Model parameters required for running GLACIER are: six parameters for the two-step devolatilization mechanism ($Y_{1,2}$, $A_{1,2}$ and $E_{1,2}$), three parameters for the one-step coal oxidation process (n, A_c and E_c) and a set of parameters for a comprehensive gas-phase NO_x mechanism: VMNFR, ZEDAH and ZEDA. VMNFR defines the nitrogen division between volatile matter and coal-char. ZEDA is the parameter that partitions the formation of volatile matter nitrogen between HCN and NH_3. ZEDAH specifies the fraction of char nitrogen that is converted to NO_x. This amounts to a total of 12 parameters which values for Adaro coal could not be found in the literature. All of these parameters can be varied in the GLACIER program to obtain the best agreement with the experimental data.

In the methodology we developed a method to predict combustion behavior and pollutant emissions from utility boilers that fitted our test facility results, which were then used, without any changes, for the simulation of the boilers' conditions. As for the parameters concerning devolatilization and char combustion (Y_1, Y_2, A_1, A_2, E_1, E_2, A_c, n and E_c) they were found not to depend on the stoichiometric ratio (SR) at the burner, and the same parameters could be used for SR in the range 0.8–1.2. Unfortunately, this was not the case for the parameters concerning NO_x formation (VMNFR, ZEDA and ZEDAH), which clearly depended on SR. We found two sets of parameters, one that relates to fuel-lean conditions in the SR range 0.98–1.2, and one that relates to fuel-rich conditions in the SR range 0.8–0.92. The model parameters found to provide the best agreement between measurement data and simulations are presented in Table 2. Different values of these parameters are found in the literature [9–15] and even vary for a certain coal, depending on its firing configuration.

The approach described here determines a simplified kinetics model. While it cannot be said that the kinetic parameters used in the model will correspond to the combustion rate of a single particle of coal, these parameters do describe the combustion behavior of a "macroscopic" sample of the tested coal. For the goal of predicting the combustion behavior in a utility boiler furnace, this simplified model used with the GLACIER code gave good results.

2.2. Operational parameters – EXPERT system

The on-line supervision system used by IEC, EXPERT system, is described in detail elsewhere [6]. The basic functional aim of the supervision system is to quantify the per-